## Dr. Bruce Kaiser XRF Analysis

In the heading "Caretaker" I have briefly explained why I was looking for the XRF analyses.

In my research, I became aware that a handheld XRF-devise was available from the Bruker Company; the latest version of that instrument was the Tracer III SD. Fortunately a Major University in the South-East did have that instrument. They informed me that if I brought Catherine Howard in Stained Glass to their laboratory, analysis could be performed with the Tracer III SD and so it happened.

A few days later I received the test results.

Not a chemist by profession, but still having some knowledge about the basics of the organic and inorganic chemistry, I do understand how XRF works. Also I have a basic understanding of the errors that can occur when the settings of the instrument are not properly met for a specific application. In short, analyzing scrap metal is quite different from analyzing stained glass.

Hence, when I started to examine the data from the University, I realized that comparing those numbers with the data from Dr. Robert H. Brill's "CHEMICAL ANALYSES of EARLY GLASSES" Volume 2 would be a monumental task considering the complexity of the glass compositions. To make it worse, I found an unexplainable discrepancy in the elemental data.

Feeling stuck, I searched for options at the Bruker website and became aware that the Tracers were developed by Dr. Bruce Kaiser. We have a saying in Holland: "If you don't shoot, you always miss". With that in mind, I contacted Dr. Bruce Kaiser by email and explained my "what, why and now what".

In regards with this adventure, it was the best thing I ever did. Dr. Bruce Kaiser answered promptly and very comprehensive but most educational as well. He debunked right away some of my misconceptions and included some "light" reading for better understanding of the principles of XRF. We exchanged a few more emails clarifying some more details, whereby Dr. Bruce Kaiser told me that Bruker does not have a loan/rent program for the Tracer III SD but in case I could take Catherine Howard in stained glass cross country, he would be happy to do the analysis in his lab. So again I travelled with Catherine Howard in stained glass but now to the West Coast to have it analyzed.

Meeting Dr. Bruce Kaiser in person was a real delight. After all, a lot of world famous people have the tendency to become distanced from the hoi polloi. Definitely not the case with Dr. Bruce Kaiser. Needless to say that we had a really good time.

A few days later I received his report. It became crystal clear that an intrinsic knowledge of glass is the key to the interpretation of XRF data. These are the net numbers of photons from each element in 60 seconds:

net photons in 60 sec per element         Ag           back scan-0001         169           back scan-0002         292           back scan-0003         363           back scan-0004         303           back scan-0005         305           back scan-0005         305           back scan-0006         514           back scan-0007         468           back scan-0008         230           back scan-0001         277           back scan-0010         277           back scan-0011         473           back scan-0012         388           back scan-0013         506           back scan-0014         101           back scan-0015         272           back scan-0017         195           back scan-0018         200	As 2495 2642 2664 3467 3365 3920 3842 3739 3952 4221 4453 4844 4830 5403 5997 6227	Ba 144 255 183 246 313 262 224 347 257 293 356 210 148 354 190	Ba L1 357 301 302 410 301 271 377 306 301 368 310 357 397 394	Ca 1236 1113 1015 920 858 961 773 809 834 759 648 552 532 497	Co 3436 3505 3363 3301 3371 3223 3249 3192 3340 3168 3054 3054 3054	Cr 1737 1980 2208 2177 2336 2434 2349 2509 2470 2786 2983 2972 3387	Cu 516 586 655 1653 3133 3055 2927 3404 3892 5763 6909 7442	Fe 6693 7475 8095 8076 9578 11133 10905 10609 11172 12137 14053 15108	Ga 418 317 532 550 763 554 584 605 572 631 704	к 395 315 202 161 175 192 167 242 97	Mn 46752 44911 43215 42384 41464 42036 41341 42362 42046 40685 39220	Ni 376 389 382 347 405 339 359 362 365 305 282	Pb L1 47025 54216 60686 63530 71403 72702 73152 73720 73720 73526 81604 86774	Rb 269 168 433 257 278 306 324 431 441 227 283	Sb 758 896 802 732 519 760 624 625 599 762 865	Si 202 181 176 110 199 132 134 180 107 133 161	Sn 214 324 293 115 83 216 108 226 121 164 286	Sr 1234 1060 1143 1123 1175 1187 1189 1086 1173 1200 1283	Ti 45 33 28 29 60 45 7 40 89 60 82	Zn 2217 2239 2358 2414 3066 4028 3902 3857 3877 4375 5344
back scan-0002         292           back scan-003         363           back scan-004         303           back scan-005         305           back scan-005         305           back scan-006         514           back scan-007         468           back scan-007         468           back scan-007         468           back scan-008         320           back scan-009         352           back scan-001         277           back scan-001         277           back scan-0012         388           back scan-0013         506           back scan-0014         101           back scan-0015         272           back scan-0016         239           back scan-0017         195           back scan-0018         332           control         205           back scan-0018         321           back scan-0017         195           back scan-0018         322           back scan-0017         195           back scan-0018         322           back scan-0018         322	2642 2664 3467 3365 3920 3842 3739 3952 4221 4453 4844 4830 5403 5997	255 183 246 313 262 224 347 257 293 356 210 148 354	301 302 410 301 271 377 306 301 368 310 357 397	1113 1015 920 858 961 773 809 834 759 648 552 532	3505 3363 3301 3371 3223 3249 3192 3340 3168 3054 3037 2814	1980 2208 2177 2336 2434 2349 2509 2470 2786 2983 2972	586 568 655 1653 3133 3055 2927 3404 3892 5763 6909	7475 8095 8076 9578 11133 10905 10609 11172 12137 14053	317 532 550 763 554 584 605 572 631 704	315 302 235 202 161 175 192 167 242	44911 43215 42384 41464 42036 41341 42362 42046 40685	389 382 347 405 339 359 362 365 305	54216 60686 63530 71403 72702 73152 73720 73720 75326 81604	168 433 257 278 306 324 431 441 227 283	896 802 732 519 760 624 625 599 762 865	181 176 110 199 132 134 180 107 133	324 293 115 83 216 108 226 121 164	1060 1143 1123 1175 1187 1189 1086 1173 1200	33 28 29 60 45 7 40 89 60	2239 2358 2414 3066 4028 3902 3857 3877 4375 5344
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back scan-0004         303           back scan-0005         305           back scan-0006         514           back scan-0007         468           back scan-0008         230           back scan-0009         352           back scan-0010         277           back scan-0011         473           back scan-0012         388           back scan-0013         506           back scan-0014         101           back scan-0015         272           back scan-0017         195           back scan-0018         332           met photons in 60 sec per element         Ag	3467 3365 3920 3842 3739 3952 4221 4453 4844 4830 5403 5997	246 313 262 224 347 257 293 356 210 148 354	410 301 271 377 306 301 368 310 357 397	920 858 961 773 809 834 759 648 552 532	3301 3371 3223 3249 3192 3340 3168 3054 3037 2814	2177 2336 2434 2349 2509 2470 2786 2983 2972	655 1653 3133 3055 2927 3404 3892 5763 6909	8076 9578 11133 10905 10609 11172 12137 14053	550 763 554 584 605 572 631 704	235 202 161 175 192 167 242	42384 41464 42036 41341 42362 42046 40685	347 405 339 359 362 365 305	63530 71403 72702 73152 73720 75326 81604	257 278 306 324 431 441 227 283	732 519 760 624 625 599 762 865	110 199 132 134 180 107 133	115 83 216 108 226 121 164	1123 1175 1187 1189 1086 1173 1200	29 60 45 7 40 89 60	2414 3066 4028 3902 3857 3877 4375 5344
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back scan-0011     473       back scan-0012     388       back scan-0013     506       back scan-0014     101       back scan-0015     272       back scan-0016     239       back scan-0017     195       back scan-0018     332       met photons in 60 sec per element     Ag	4453 4844 4830 5403 5997	356 210 148 354	310 357 397	648 552 532	3054 3037 2814	2983 2972	5763 6909	14053	704					283	865					5344
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back scan-0016 239 back scan-0017 195 back scan-0018 332 net photons in 60 sec per element Ag		190			2693	3437	7311	16201	902	62	33933	252	104490	325	733	135	176	1214	8	6758
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back scan-0018 332 net photons in 60 sec per element Ag		282	333	340	2441	4166	8708	18015	1013	64	28873	288	120286	389	779	119	319	1259	42	7359
net photons in 60 sec per element Ag	6754	203	410	310	2312	4440	8292	18449	1082	73	26163	202	129870	307	646	139	197	1335	1	7266
	7977	189	353	265	2120	4906	8184	18899	1210	46	24824	266	138579	587	588	99	230	1290	1	7054
vest scana-0001 427	As	Ва	Ba L1	Ca	Co	Cr	Cu	Fe	Ga	к	Mn	Ni	Pb L1	Rb	Sb	Si	Sn	Sr	п	Zn
	970	-1	29	2308	43	14	282	917	8	506	97	7	7125	184	789	180	228	388	31	5466
vest scana-0002 455	1022	159	32	2206	12	45	304	880	0	516	61	25	7039	451	764	242	102	545	29	5482
vest scana-0003 419	1215	156	4	2050	23	22	261	870	0	497	87	49	6777	296	728	230	73	407	81	5502
vest scana-0004 433	1232	135	44	2111	29	33	256	946	-2	507	80	21	6705	378	748	201	163	488	30	5361
vest scana-0005 444	1204	223	15	2134	43	9	287	914	-1	514	61	35	6837	227	817	206	67	484	68	5506
vest scana-0006 364	1127	123	29	2124	4	7	277	881	0	528	54	3	6816	366	721	199	107	486	57	5499
vest scana-0007 310	1085	156	51	2037	35	29	294	796	19	476	88	22	6696	279	791	146	297	440	24	5427
vest scana-0008 409		256	66	1974	12	20	290	896	13	508	85	8	6822	296	751	187	174	391	5	5264
vest scana-0009 224	954			2138	9	22			36	495	50		6693	273	824	175	171	404	22	5396

Dr. Bruce Kaiser was well aware that representation of data in this format is impossible to understand for most. Therefore he used bar graphs to make it easier for us, common folks. In the next pages he gives an overview of the glasses as they were used through the centuries. With bar graphs he shows how much of the elements like Arsenic (As), Chromium(Cr), Manganese(Mn), Copper(Cu), iron(Fe), Lead(Pb), and Zinc(Zn) are present in the various pieces of glass.

He then describes how the blue background has a high concentration of Copper on front and back, indicating that the glass is true blue glass and not stained blue. After that he gives a brief explanation as to the use of Silver Stain for the color yellow. His graph shows a high concentration of Silver(Ag) on the medallion.

## Dr. Bruce Kaiser comes to the most important aspect of the analysis.

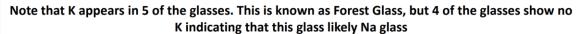
## Composition, manufacture and distribution

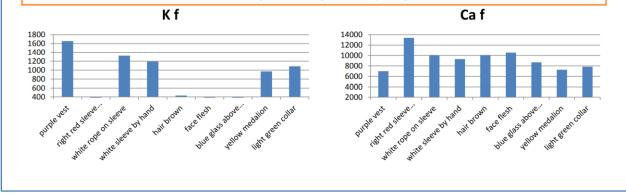
Prior to c.1000, most coloured glass was of a soda-lime-silica composition. In Northern Europe soda glass was eventually almost totally superseded by potash-lime-silica glass (Forest glass). Forest glass continued to be used in stained glass for the duration of the medieval period until soda glass again began to be used in the 16th century.

The potash ( $K_2O$ ) found in Forest Glass was derived from wood ash. In *De Divers Artibus*, Theophilus describes the use of beech wood as the preferred source of ash. Other plant matter, such as bracken, was also used.<sup>[13</sup> As well as containing potash, beech ash comprises an assortment of compounds including iron and manganese oxides, which are particularly important for generating colour in glass.

Medieval stained glass panels could be created either by the cylinder blown sheet or crown glass (window) method.

Forest glass was manufactured in Burgundy and Lorraine near the Rhein; in Flanders; and in Normandy, in the Seine and Loire Valleys. It was distributed throughout mainland north-west Europe and Britain in the form of ready-made sheets. The application of painted decoration to and final shaping of the sheets was carried out at glass working centres close by the final destination of the glass.





After his explanation of differences between Forest glass and Soda lime glass, this image shows on the left side that some of the glass contains Potassium (K) "Kalium" while it's absent in other pieces. It is undisputable that both kinds of glass were only used in the transition period during the first part of the 16th. century.

His conclusions draw some interesting facts. Indeed there is only one known stained glass artwork attributed to Hans Holbein Jr. at the Getty Museum as:

"A Premonstratensian Canon"

https://www.getty.edu/art/collection/objects/220332/possibly-after-hans-holbein-the-younger-a-premonstratensian-canon-swiss-about-1520/

Moreover, only a few stained glass artworks from his father, Hans Holbein Sr, are known and they are among the most extremely beautiful stained glass windows ever made.